REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-01-

0050

1. REPORT DATE *(DD-MM-YYYY)* 28/12/00	**2. REPORT TYPE** Final Technical report	**3. DATES COVERED** *(From - To)* 3/1/99-2/28/00
4. TITLE AND SUBTITLE Integrated Instrumentation for Plastic Laser Materials Development		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER F49620-99-1-0207
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Alex K-Y. Jen		**5d. PROJECT NUMBER**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Northeastern University	Department of Chemistry Northeastern University Boston, MA 02115	**8. PERFORMING ORGANIZATION REPORT**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dr. Charles Y-C. Lee AFOSR/NL 801 N. Randolph St. #732 Arlington, VA 22203-1977		**10. SPONSOR/MONITOR'S ACRONYM(S)**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The objective of this DURIP program is to develop an integrated instrumentation package that combines the capability of performing the measurements of charge mobility, conductivity, photo- and electro-luminescence emission spectra, luminous efficiencies, as well as the thresholds of optically pumped lasing. By integrating these testing functions together, it will provide a very efficient mechanism to evaluate potential polymer systems for the fabrication of laser diode devices.

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT Unclas	**b. ABSTRACT** Unclas	**c. THIS PAGE** Unclas		7	**19b. TELEPHONE NUMBER** *(include area code)* (206) 543-2626

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

END-OF-THE-YEAR-REPORT

for

GRANT #, F49620-99-1-0207

Integrated Instrumentation for Plastic Laser Materials Development

Alex K-Y. Jen

Department of Chemistry
Northeastern University
Boston, MA 02115

Current Address: Department of Materials Science & Engineering
Box 352120
University of Washington, WA 98195-2120

December 26, 2000

1. Introduction

There is a growing interest in ultilizing conjugated polymers as electroluminescent (EL) materials in large area flat panel display applications. They possess significant processing, mechanical, thermal, and size advantages over those made by evaporation methods. In addition, it is possible to fabricate full color displays utilizing the broad spectral range of emission colors available from semiconducting luminescent polymers and organic molecules. Many conjugated polymers are luminescent materials with a Stoke shift that separates emission sufficiently far from the absorption edge that self-absorption is minimal. Because of the large joint density of states associated with the direct π to π^* (interband) transition of these quasi-one-dimensional semiconducting polymers, the absorption coefficient (α) is large, typically $\alpha \geq 10^5$ cm^{-1}. To the first order, the cross-section for stimulated emission (SE) is the same as that for absorption, so the gain length should be essentially equal to the absorption length scaled by the fraction of chromophores in the excited state. Therefore, an inverted population can be achieved by pumping the π to π^* transition; this does not simultaneously stimulate emission because the absorption and emission are spectrally separated. Thus, luminescent conjugated polymers offer promise as novel laser materials with gain lengths in the micron regime.

Interest in using these polymers as solid state laser materials was initiated by the demonstration of the optically pumped gain narrowing in dilute blends of MEH-PPV in polystyrene. Subsequently, many new polymers have been developed to show similar spectral narrowing above threshold in the solid state. Achievement of gain narrowing requires that two criteria be fulfilled: 1) The active polymer medium must exhibit SE under optical or electrical excitation; 2) some type of resonant structure must enable the emitted photons to travel a distance greater than the gain length in the excited polymer. Appropriate structures for amplified spontaneous emission (ASE) include planar waveguides with distributed feedback and microcavities.

Although the optically pumped lasing of conjugated polymers offers promise in the construction of laser diodes with such materials, sufficient carrier concentrations must be produced by electrical pumping in order to render any of these devices for practical use. Based on the threshold optical pump power for the establishment of gain, several impotant criteria need to be met in order to achieve electrically pumped polymer lasers: 1) develop EL materials with high quantum efficiency; 2) reach high transient current densities; 3) construct a laser diode with

a high-Q resonant cavity or improved waveguiding structures. Our approach in developing suitable materials for plastic lasers is based on: 1) design, synthesis and evaluation of suitable EL polymer systems ; 2) screening and evaluation of their stimulated emission capabilities and for their threshold of gain narrowing under optical pumping; and 3) teaming up with laser physicists (Professor Alan Heeger's group at U. C. Santa Barbara) to test the feasibility of demonstrating electrically pumped lasing.

Although different groups are developing the basic luminescent molecules, polymeric materials, processes, and devices, they measure and report their results based on different specific and individual tests. Due to the different test procedures and measurement methods, it is difficult to make comparisons between the materials. Thus, selecting the most promising development path becomes difficult. To speed up the tedious selection process, it is highly desirable to have an integrated instrumentation that provides the necessary information such as charge mobility, brightness, photo- and electroluminescence, current-electric field characteristics, and thresholds of optically pumped lasing, in a short time span.

2. Objective

The objective of this DURIP program is to develop an integrated instrumentation package that combines the capability of performing the measurements of charge mobility, conductivity, photo- and electro-luminescence emission spectra, luminous efficiencies, as well as the thresholds of optically pumped lasing. By integrating these testing functions together, it will provide a very efficient mechanism to evaluate potential polymer systems for the fabrication of laser diode devices.

3. Impact to the new research programs on LED/Laser materials at Northeastern University

The integrated instrumentation has greatly enhanced the quality and capability of the new conjugated materials research at Northeastern University (NU) to evaluate suitable LED/laser material system properties. The new facility established by Professor Alex Jen possesses the capability of synthesizing and characterizing novel conjugated polymers. This integrated instrumentation has helped to guide the synthetic effort to fine-tune the properties of molecular structures and establish desirable material system properties of light-emitting polymers, and thus, directly impact the fabrication of highly efficient EL/lasing devices. Seventeen light-emitting

polymers related papers have been published in the refereed journals based on the characterization results derived from this set-up. In addition, this facility has provided very useful services to researcher (Professor Timothy Swager-MIT, Professor Lin Pu-U. of Virginia, Professor Larry Dalton-U. of Washington) that are supported by DoD's funding agency. The capability of this integrated instrumentation includes a Coherent Ti:Sapphire femto-second pulse laser system, a Jobin Yvon monochrometer and CCD detector, a HP 500 MHz oscilloscope, and an optical table breadboard and isolating support systems.

4. Interface between the instrumentation and the existing facility for electro-optic (E-O) and light-emitting materials research at Northeastern University

This integrated instrumentation interfaces very well with the existing E-O and LED materials research facility at Northeastern University (NU) to provide strong capability to evaluate organic photonic/opto-electronic material properties. One of the new research program proposed by both professors Alex Jen aims at demonstrating an integrated all polymer LED/E-O device by using organic conjugated polymers as both a light source (plastic laser) and a photodetector, and using NLO polymer channel waveguides as an E-O switching device. This instrumentation greatly enhances the capability of quickly developing/screening both LED and E-O materials systems to ensure the greatest chance of success. In the area of polymer characterization, the facility at NU is equipped with the instruments such as TGA and DSC for thermal analysis; GPC and HPLC for polymer molecular weight measurement; and Dektak instrument for measuring thin film thickness. In addition, FT-IR and UV-Vis-Near IR spectrometer were used to determine the thermal stability of the E-O polymer thin films. In the areas of optical and electrical characterization, the micromanupilator device could be used to cure (up to 400 °C) and pole NLO thin films and channel waveguides; Metricon prism coupler could measure refractive index, optical loss, and thickness of polymer thin films; lock-in amplifier and the associated electronic system could measure optical and electro-optic signal generated by LED/E-O materials. This integrated instrumentation will help to bridge between the effort of evaluating E-O and LED polymeric material system properties, and thus, directly impact the fabrication of all polymer laser devices.

5. Research training of students

The highly interdisciplinary nature of the program to develop high performance light-emitting materials for LED/laser device applications, the outstanding faculty and institutions involved, and connections with high technology device companies and DoD laboratories ensure a rich educational environment for the graduate students, postdoctors, and undergraduate

students involved. Students are active members involved in closely integrated material synthesis, characterization, and device fabrication. Students associated with this program will emerge with a unique background and complement of skills. The ability to communicate with and work with academic, government, and industrial researchers in other disciplines towards a common goal will uniquely qualify them for the technical workforce of the future.

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